Instabilities in Cellular Solids and the Role of Dispersity in Geometric Structure

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Failure and the often-associated instabilities in materials with microstructure are manifested in many different ways. The occurrence of an instability can be the precursor to shear band formation, pore and crack nucleation, and ultimately material failure, so an understanding of the relationships among microstructure, continuum-scale mechanical response, and stability is essential in material and engineering component design.

Geometric structures in cellular solids span the spectrum from highly ordered to strictly random. If the degree of dispersity in the underlying cellular geometry is low, failure in these materials typically manifests itself as localized deformation; for example, the collapse of cells. For materials with a high degree of dispersity, however, the stress can become a monotonically increasing function of strain, and thus, no critical point is reached, and the mechanical response remains stable through all regimes of compressive deformation. The primary objective of this investigation is to study the behavior of cellular materials ranging over the spectrum of geometric structures from highly ordered to highly disordered, and to explore the corresponding transition from unstable to stable mechanical response.

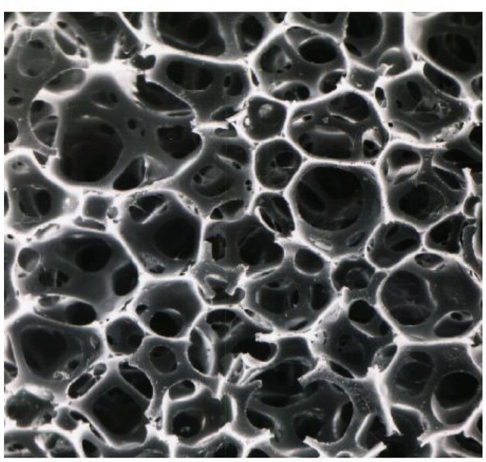

Fig. 1.
A scanning electron micrograph of a low-density, open-cell, polyurethane foam showing the intricate, disordered, geometric structure at the cellular scale. Material provided courtesy of the Dow Chemical Company, and micrograph provided courtesy of David J. Alexander, MST-6.

An advanced constitutive model is developed and used to investigate the stability of cellular solids [1]. Stochastic variation in cellular-scale geometric structure and material properties is considered through the use of probability density functions for the associated model parameters. Using this approach, ordered cellular structures are represented using monodisperse distributions, while disordered cellular structures with varying degrees of dispersity are represented using other appropriate distribution functions.

Results demonstrate a general stabilizing effect of dispersity in geometric structure on the continuum-scale mechanical response of cellular materials. Consistent with previous investigations, dispersity in geometric structure is shown to have no effect on the initial elastic properties of the cellular materials under investigation. For deformations occurring prior to any instability, however, increasing dispersity is accompanied by decreasing stiffness.

No additional information might lead one to believe that dispersity in geometric structure has an overall detrimental effect on the mechanical response of cellular materials. The results of the present investigation, however, show that as the dispersity increases, the critical strains increase, the extent of localized deformation diminishes, and the materials stiffen for deformations occurring after the critical load. Most notably, the mechanical response of the materials with the highest degrees of dispersity in their cellular structures remains stable for all compressive deformations through full densification.

The results are consistent with trends shown in a wide range of analytical, numerical, and experimental studies of various cellular solids, suggesting that the stochastic constitutive model can be used to quantify the influence of cellular-scale geometric and material variability on the mechanical response, the stability, and the onset of failure in cellular materials. The constitutive model also provides useful information regarding the initial cellular-scale structural configurations in these materials, and the potential for these configurations to admit unstable behavior and eventually succumb to failure. Such information could prove valuable in tailoring these materials at the cellular scale for increased load-carrying capacity and reduced susceptibility to failure, possibly shifting the processing and manufacturing paradigm for this class of materials from properties by trial and error to properties by design.

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[1] M.W. Schraad, "The Influence of Dispersity in Geometric Structure on the Stability of Cellular Solids," *Mech. Mater.*, submitted (2006).

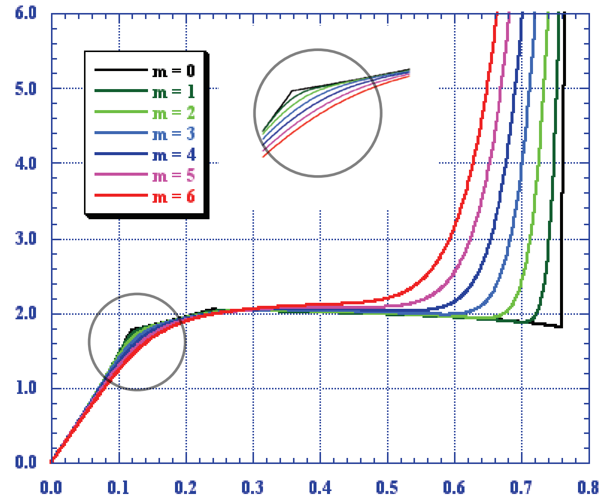

Fig. 2.
The influence of dispersity in geometric structure on the simulated continuum-scale mechanical response of a low-density, open-cell, polyurethane foam. Results for mono-disperse distributions are plotted using a black line, while the results obtained for values of the geometric dispersion parameter ranging from 1–6 are plotted using various colored lines as indicated.

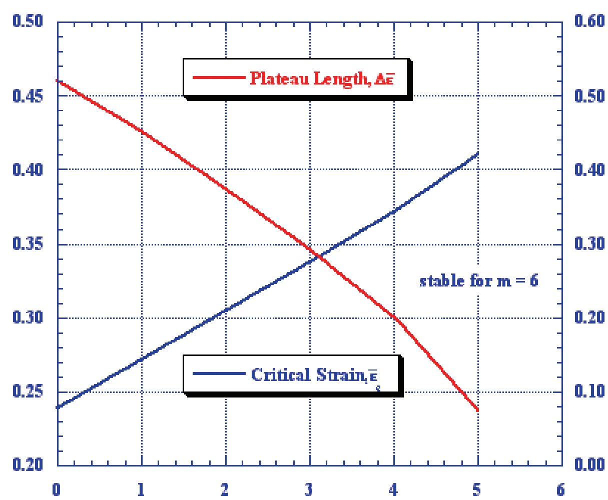

Fig. 3.
The influence of dispersity in geometric structure on the critical strain and load-plateau length. Notice that for m > 5, the load plateau diminishes altogether, as the stress becomes a monotonically increasing function of strain. For m = 6, the mechanical response remains stable for all uniaxial compressive deformations.

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